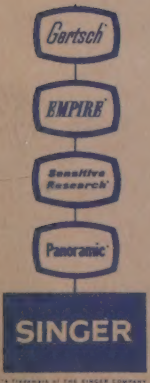
INSTRUCTION BOOK
for
COAXIAL SWITCH RATIOTRANS®



Precision electrical and electronic instruments for measurement

THE SINGER COMPANY • METRICS DIVISION

INSTRUCTION BOOK
for
COAXIAL SWITCH RATIOTRANS®

Gertsch
EMPIRE
Sensitive Research
Panoramic
SINGER

*A Trademark of THE SINGER COMPANY

Precision electrical and electronic instruments for measurement

THE SINGER COMPANY • METRICS DIVISION

Rev. 5/66

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THE SINGER COMPANY, METRICS DIVISION, warrants each new instrument to be free from defects in material and workmanship, effective after delivery to the original purchaser as follows:

*Commander** Instruments: Potentiometers, Bridges,
Volt Ratio Boxes and Standard Resistors.....5 years
*Sensitive Research** Electrical Indicating Instruments.....2 years
Other Electrical and Electronic Measuring Instruments.....1 year

Repair or replacement (at our option) without charge (F.O.B. factory) will be effected when our examination satisfactorily indicates that defects are due to workmanship or materials. Electron tubes, semiconductors, batteries, fuses, lamps, thermoelements, and *RatioTran** potentiometers are excluded from warranty coverage. Warranty returns must first be authorized by the factory.

If the instrument or any portion thereof, has been abused, misused, damaged by accident or negligence, or if any serial number or seal has been removed or altered, the warranty is void.

This warranty is in lieu of all other obligations or liabilities expressed or implied and The Singer Company neither assumes, nor authorizes any person to assume for them, any other liability in connection with sales of instruments manufactured by The Singer Company, Metrics Division.

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Instruments should be returned only on prior written authorization from the Singer Representative or the factory(1). Warranty repair will be made upon written request. Please provide the following information in order to expedite our processing of your instrument:

1. Model or Type
2. Serial Number
3. Description of trouble(2)
4. Test instruments used
5. Approximate date instrument was placed in operation
6. Approximate number of hours of use
7. Has maintenance action been previously requested?
8. Other comments

Upon receipt of this information our Service Department will send you service data or shipping instructions. Upon receipt of shipping instructions forward the instrument to the factory prepaid. If requested, an estimate of charges will be made before work begins.

(1) Contact Metrics Division, Bridgeport, Connecticut for *Commander**, *Empire**, *Panoramic**, and *Sensitive Research** instruments. Contact Metrics Division, Los Angeles, California for *Gertsch** instruments.
(2) Include data on symptoms, measurements taken, suspected location of trouble, maintenance action taken, and any other relevant data.

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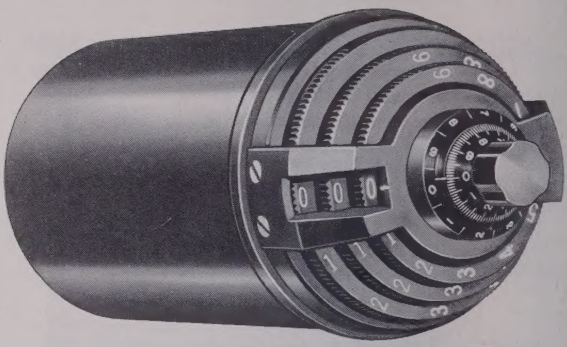
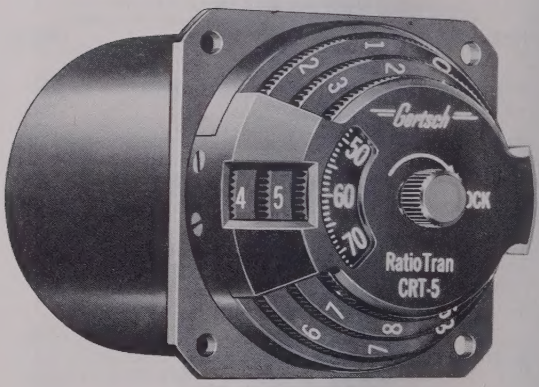


CRT-4 (Servo mount shown)



CRT-5 (Flange mount shown)

Figure 1-1. Coaxial Switch Ratiotrans.

SECTION I
GENERAL DESCRIPTION

1-1. PURPOSE.

1-2. The Ratiotrans are inductive voltage dividers providing an output voltage which is in a precise ratio to an input voltage. The Ratiotran can be used to generate an output ratio, to measure the output voltage of a unit under test, or to duplicate the voltage ratio output required of a unit under test.

1-3. MIL SPEC UNITS (Models CRT-3, 4, 5, and 6)

1-4. These sub-miniature instruments were designed to meet military specifications, and to operate under severe environmental conditions. All models are certified to MIL Specs for vibration, shock, salt spray, drip proof, fungus, and humidity.

a. The CRT-3 & 6 have 5-place resolution, obtained by a 3-decade ratio transformer and a 1-turn interpolating potentiometer.

b. CRT-3 has positive dial lock.

c. The CRT-4 uses a 10-turn potentiometer with dial lock, and provides 6-place resolution.

d. The CRT-5 has 2 decades of ratio transformers, and a 1-turn interpolating potentiometer with dial lock.

1-5. COMMERCIAL UNITS (Models CRT-1, 2, 11, & 12)

1-6. These models are recommended for applications not requiring military specifications and extremely small size. Units are identical in all other characteristics to the MIL SPEC models, and offer excellent performance in an economical price range.

a. CRT-1 and -2 have maximum ratios of 1.000.

b. CRT-11 and -12 have maximum ratios of 1.1110.

c. The CRT-1 and -11 provide a 6-place digital readout, with a three-decade ratio transformer and a 10-turn interpolating potentiometer with dial lock.

d. The CRT-2 and -12 have a 1-turn potentiometer providing effective 5-place readout. Where extremely low effective series impedance is desirable, Models CRT-2A and -12A are available.

1-7. The ratio accuracy of the units is based upon the use of a toroidal autotransformer which is not affected by age or environmental conditions. Accuracy is traceable to National Bureau of Standards.

1-8. MOUNTING.

1-9. All units are designed for universal servo ring or flange mount. Refer to figure 1-3 or 1-4 for a flange mount hole pattern.

Table 1-1. (MIL SPEC UNITS)

SPECIFICATIONS

Shock MIL-S-901B
(5 ft. drop, 400 lb. hammer)

Salt Spray MIL-E-5272A

Drip Proof MIL-STD-108

Vibration:
Operating MIL-STD-167, Type I
Non-operating MIL-E-4970, Proc. III

Sand and Dust MIL-E-4970, Proc. I

Altitude MIL-E-4970, Proc. I

Explosion MIL-E-4970, Proc. I

Fungus MIL-E-5272

Humidity MIL-STD-202A

High Temp.
Operating +52°C
Non-operating +71°C

Low Temp.
Operating −18°C
Non-operating −54°C

Dielectric Strength 900 V RMS, 60 cps

ACCURACY OF INDICATED RATIO

MODEL	50-3000 cps	3000-10,000 cps
CRT-1, CRT-2, CRT-3 CRT-6, CRT-7, CRT-11	$\pm(.001 + \frac{.0006\%}{\text{Ratio}})$	$\pm(.01 + \frac{.006\%}{\text{Ratio}})$
CRT-2A, CRT-3A CRT-5A, CRT-12A	$\pm(.002 + \frac{.001\%}{\text{Ratio}})$	$\pm(.02 + \frac{.001\%}{\text{Ratio}})$
CRT-5	$\pm(.005 + \frac{.005\%}{\text{Ratio}})$	$\pm(.01 + \frac{.005\%}{\text{Ratio}})$

Model	Type	Frequency Range	Resolution	Terminal Linearity	Input Voltage (f in cps)	Max. Effective Series Output Impedance	Input Inductance (Approx.)	Weight (Lbs.)	Notes
CRT-1	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—12 ohms L—75 uh	150 henries	3½	6-place digital readout with 3-decade transformer and 10-turn interpolating potentiometer with dial lock. Max. ratio 1.000.
CRT-2	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—12 ohms L—75 uh	150 henries	3½	5-place readout with 3-decade transformer and 1-turn potentiometer. Max. ratio 1.000.
CRT-2A	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—5 ohms L—75 uh	150 henries	3½	5-place readout with 3-decade transformer and 1-turn potentiometer. Max. ratio 1.000.
CRT-3	MIL Spec.	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—14 ohms L—75 uh	150 henries	2	5-place readout with 3-decade transformer and 1-turn potentiometer with dial lock.
CRT-3A	MIL Spec.	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—5 ohms L—75 uh	150 henries	2	5-place readout with 3-decade transformer and 1-turn potentiometer with dial lock.
CRT-5	MIL Spec.	50-10,000 cps	Continuous	.005%	.35 f 350V max.	R—9 ohms L—50 uh	150 henries	2	4-place readout with 2-decade transformer and 1-turn potentiometer.
CRT-6	MIL Spec.	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—14 ohms L—75 uh	150 henries	2	5-place readout with 3-decade transformer and 1-turn potentiometer.
CRT-6A	MIL Spec.	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—5 ohms L—75 uh	150 henries	2	5-place readout with 3-decade transformer and 1-turn potentiometer.
CRT-7	MIL Spec.	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—14 ohms L—75 uh	150 henries	2	5-place readout with 3-decade transformer and 1-turn potentiometer. Includes transient suppression and terminal board.
CRT-11	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—12 ohms L—75 uh	150 henries	3½	6-place readout with 3-decade transformer and 10-turn potentiometer with dial lock. Max. ratio 1.1110.
CRT-12	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—12 ohms L—75 uh	150 henries	3½	5-place readout with 3-decade transformer and 1-turn potentiometer. Max. ratio 1.1110.
CRT-12A	Comm	50-10,000 cps	Continuous	.001%	.35 f 350V max.	R—5 ohms L—75 uh	150 henries	3½	5-place readout with 3-decade transformer and 1-turn potentiometer. Max. ratio 1.1110.

Table 1-2.

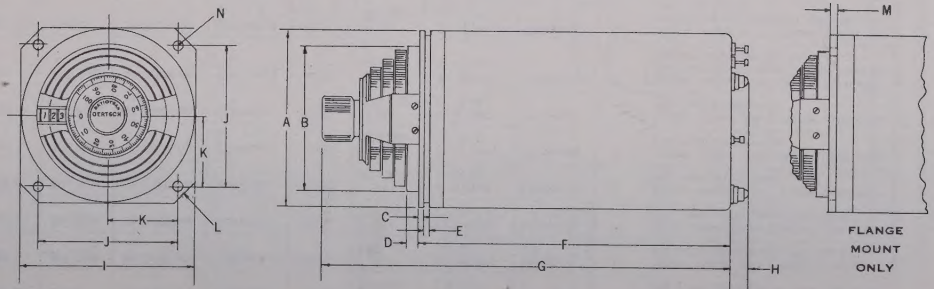


Figure 1-2.

Model	"A"	"B"	"C"	"D"	"E"	"F"	"G"	"H"	"I"	"J"	"K"	"L"	"M"	"N"
CRT-1	3.500	2.875	.094	.250	.125	6.250 ±.064	9.250 Max.	.375 ±.030	3.500 Sq. ±.030	2.740 ±.010	1.370	4.400 Dia. ±.030	.155 ±.020	.187 Hole Dia. 4-Places
CRT-2	3.500	2.875	.094	.250	.125	6.250 ±.064	8.250 Max.	.375 ±.030	3.500 Sq. ±.030	2.740 ±.010	1.370	4.400 Dia. ±.030	.155 ±.020	.187 Hole Dia. 4-Places
CRT-3	2.620 ±.020	2.490 2.510	.150 .170	.310 .350	.....	4.100 Max.	5.920 Max.	.380 Max.	2.620 Sq. ±.020	2.125 ±.010	1.062 ±.010	3.380 Dia.	.150 .170	.156 Hole Dia. 4-Places
CRT-4	2.620 ±.020	2.490 2.510	.150 .170	.310 .350	.....	4.750 Max.	6.890 Max.	.380 Max.	2.620 Sq. ±.020	2.125 ±.010	1.062 ±.010	3.380 Dia.	.150 .170	.156 Hole Dia. 4-Places
CRT-5	2.620 ±.020	2.490 2.510	.150 .170	.310 .350	.....	4.170	5.920 Max.	.380 Max.	2.620 Sq. ±.020	2.125 ±.010	1.062 ±.010	3.380 Dia.	.150 .170	.156 Hole Dia. 4-Places
CRT-6	2.620 ±.020	2.490 2.510	.150 .170	.310 .350	.....	4.200	6.020 Max.	.380 Max.	2.620 Sq. ±.020	2.125 ±.010	1.062 ±.010	3.380 Dia.	.150 .170	.156 Hole Dia. 4-Places

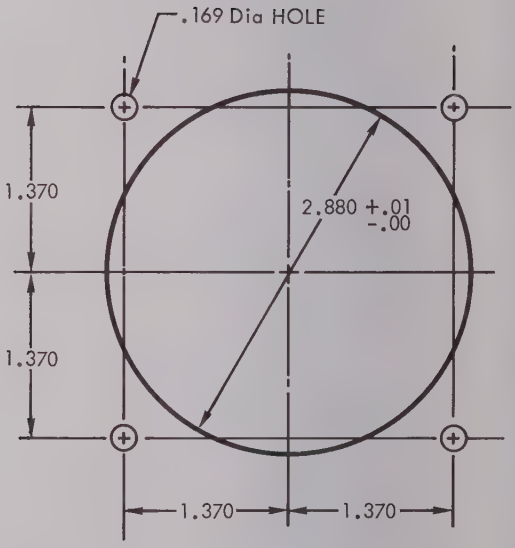
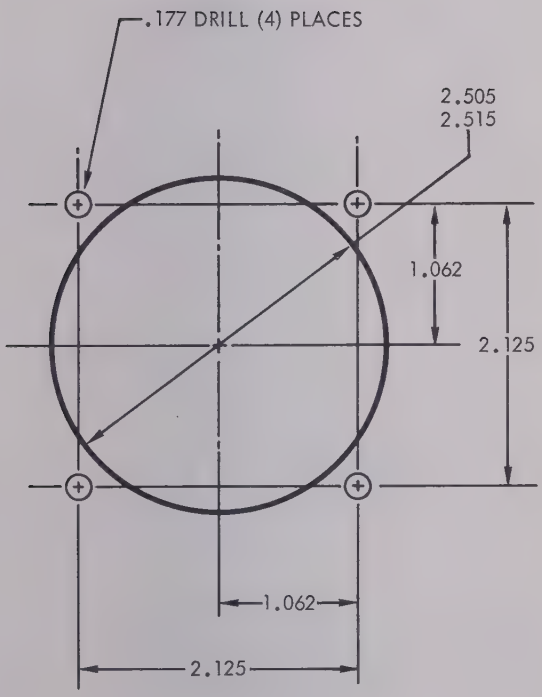


Figure 1-3. Hole Pattern for Mounting CRT-1, 2, 11, and 12.



NOTES:

1. All holes shall be located within 0.010 of true position.
2. If painted, increase hole diameters for paint thickness.

Figure 1-4. Hole Pattern for Mounting CRT-3, 4, 5, 6, and 7.

SECTION II
OPERATING INSTRUCTIONS

2-1. GENERAL.

2-2. A typical application of a Ratiotran is shown in figure 2-1. The output of the Ratiotran is compared to the output of the unit under test using a null indicator such as Gertsch Model NI-3 or a phase angle voltmeter such as Gertsch Model PAV-2. When the two outputs are exactly equal, the null indicator or phase angle voltmeter indicates a null. The input-to-output voltage ratio of the unit under test may then be read from the settings of the Ratiotran.

2-3. Additional applications are included in the Engineering Bulletins which are appended to this instruction book.

2-4. OPERATION.

2-5. To operate the Ratiotran, proceed as follows:

a. Connect input or reference voltage source to the I and C terminals. Make certain input voltage is less than 0.35 times the frequency in cps of the input signal or 350 volts, whichever is less.

b. Make certain that the input voltage does not contain a dc component. DC currents of more than a few microamperes will cause saturation of the input winding. If dc voltage is accidentally applied to the unit, degauss the unit as outlined in the maintenance section.

c. Make necessary connections to the O and C output terminals.

CAUTION

Do not apply voltage across the output terminals.

d. Turn the input voltage source ON.

e. Set the Ratiotran controls to the desired ratio or to the setting required to obtain a null.

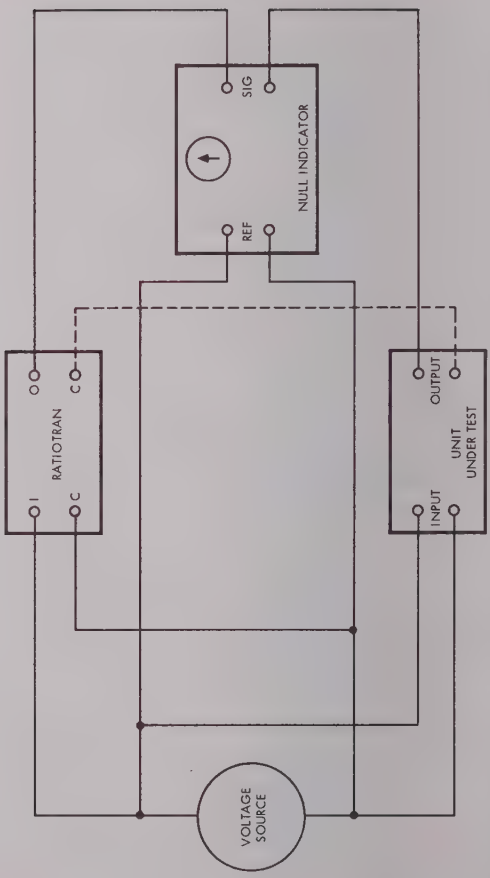


Figure 2-1. Typical Application

SECTION III
THEORY OF OPERATION

3-1. GENERAL. (See figure 3-1.)

3-2. A typical coaxial switch ratiotran consists of three transformer windings, three rotary switches, and an interpolating potentiometer. A portion of the input voltage is selected from each winding and from the potentiometer. These portions are added together to form the output voltage.

3-3. The full input voltage is applied across the first winding which is tapped to provide ten precise voltage divisions. When the first decade switch (X.1) is turned to a selected position, the lower wiper arm selects a portion of the input voltage. The two wiper arms apply reference points to the second winding which is inductively coupled to the input winding. The lower wiper arm of the X.01 switch selects a 0.01 to 0.1 portion of the input voltage which is added to the voltage selected by the X.1 switch. The process continues through the unit until the final and smallest portion of the voltage is selected by an interpolating potentiometer.

3-4. The three transformer windings are wound on a common core. Switching transients are virtually eliminated by resistors which maintain continuity between voltage steps while settings are being changed. Both the input and output of the commercial units are fused.

3-5. The center tap connection (CT) of the Mil Spec units provides the following:

a. A means for applying a balanced input with a center tap ground.

b. A means for measuring + and - ratios from the center tap position.

c. An output voltage which is exactly one half of the voltage applied across the I and C terminals.

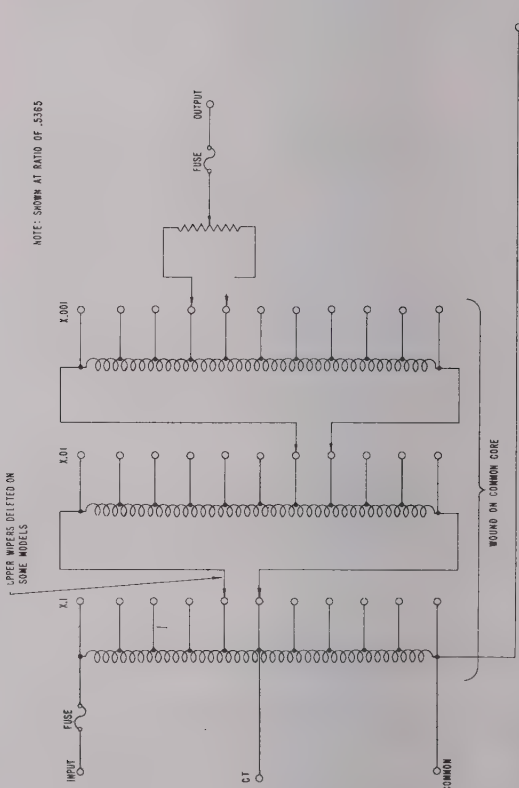


Figure 3-1. Typical Schematic

SECTION IV MAINTENANCE

4-1. GENERAL.

4-2. Since the Ratiotrans are passive devices, a minimum of maintenance is required. With the exception of cleaning switch contacts, no maintenance on a regularly scheduled basis is required. Moving parts are lubricated at the factory and should require no further lubrication.

4-3. SWITCH CONTACTS.

4-4. Once every three to six months, clean switch contacts with a good grade of solvent such as alcohol or acetone.

4-5. DEGAUSSING.

4-6. To degauss the units, proceed as follows:

a. Connect a 1K resistor in series with the input connection.

b. By means of a variac or other suitable voltage control, apply a 60 cps signal between the open end of the 1K resistor and the common terminal.

c. Starting with the voltage control at zero, increase voltage to 40 vrms.

d. Slowly decrease the voltage to zero. The period of time to reduce the voltage from 40 vrms to zero should be between 10 and 15 seconds.

SECTION V CALIBRATION

5-1. GENERAL.

5-2. The accuracy of the unit should be maintained for a period of not less than three years, provided that the unit is kept in a normal laboratory environment, has clean, low resistance contacts, and does not suffer injury or insulation damage.

5-3. Under the above conditions, the unit should only require a calibration check every three years. Under more severe conditions, the calibration period must be shortened.

5-4. This section includes two tests: an input impedance test and a simplified ratio accuracy test. Refer to Table 5-1 for a list of test equipment required. For a complete calibration procedure, refer to National Bureau of Standards Report 6738.

5-5. IMPEDANCE CHECK.

5-6. To check input impedance, proceed as follows:

a. Connect unit into test setup as shown in figure 5-1.

b. Set input frequency to 400 cps.

c. Adjust voltage source until VTVM V1 indicates twice the desired voltage through the unit under test.

d. Adjust decade resistance box until VTVM V2 shows equal indications with switch SW-1 in either position A or B.

e. Read input impedance from the decade resistance box. The input impedance shall be 200K or more.

5-7. RATIO ACCURACY TEST.

5-8. To test the ratio accuracy, proceed as follows:

a. Connect unit into test setup as shown in figure 5-2.

b. Set input frequency to 400 cps.

c. Apply input voltage of 25 vac as indicated on VTVM V1.

d. Set RT standard controls for an output reading of 0.0000000.

e. Adjust unit under test controls until the null indicator indicates a null.

f. Check the ratio indicated by the unit under test against the ratio indicated by the RT standard unit. The two ratios shall agree within the "Accuracy of Indicated Ratio" figure listed in the table of Specifications.

g. Repeat steps e through f for each switch position of the RT standard unit (0.1111, 0.2222, etc.).

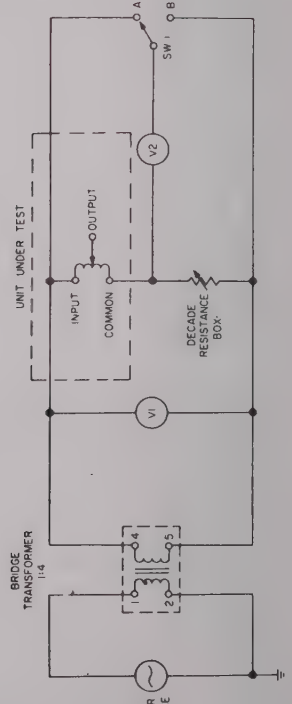


Figure 5-1. Impedance Test Setup.

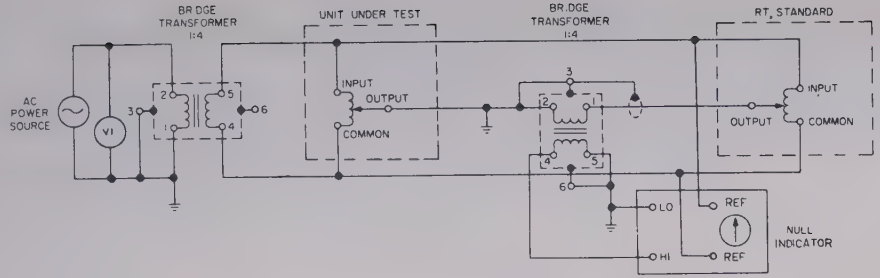


Figure 5-2. Ratio Accuracy Test.

TABLE 5-1. LIST OF TEST EQUIPMENT

NOMENCLATURE	PART NUMBER OR MODEL	APPLICATION	RANGE	ACCURACY
AC Ratio Standard	Model 1011 (Gertsch Products, Inc.)	Provides comparison standard for ratio test	1.111111 to -0.0111111 ratios	Per National Bureau of Standards Calibration Test
Bridge Transformer	Model ST100 (Gertsch Products, Inc.)	Provides voltage take-off	120 vac, 400 cps (maximum)	
Null Indicator	Model NI-3 (Gertsch Products, Inc.)	Provides means of comparing output voltage		
Decade Resistance Box		Provides voltage divider network	1 megohm range	±0.5%
Vacuum Tube Voltmeter	Model 410B (Hewlett-Packard)	Measuring voltages		±0.5%
Switch		Check voltage divider network	SPDT	

SECTION VI PARTS LIST

MODELS CRT-1, 2, 2A, 11, 12, and 12A (See figure 6-1.)

NO.	ITEM	MFG	PART NO.	-1	-2	-2A	-11	-12	-12A
1	Digital Counter	Gertsch	NP-60	1			1		
	Knob and Dial Assembly	Gertsch	AA-173		1	1		1	1
2	Yoke	Gertsch	AC-24	1	1	1	1	1	1
3	Knob and Dial Assembly	Gertsch	AC-40	1	1	1			
	Knob and Dial Assembly	Gertsch	ND-27				1	1	1
4	Knob and Dial Assembly	Gertsch	AC-39	1	1	1			
	Knob and Dial Assembly	Gertsch	ND-28				1	1	1
5	Knob and Dial Assembly	Gertsch	AC-38	1	1	1			
	Knob and Dial Assembly	Gertsch	ND-29				1	1	1
6	Shaft and Gear Assembly	Gertsch	AA-170	1	1	1	1	1	1
7	Shaft and Gear Assembly	Gertsch	AA-172	1	1	1	1	1	1
8	Shaft and Gear Assembly	Gertsch	AA-171	1	1	1	1	1	1
9	Hub and Gear Assembly	Gertsch	AA-174	3	3	3	3	3	3
10	Spacer	Gertsch	OM-384	1	1	1	1	1	1

NO.	ITEM	MFG	PART NO.	-1	-2	-2A	-11	-12	-12A
11	Switch	Gertsch	SW-23	3	3		3	3	
	Switch	Gertsch	SW-88			3			3
12	Transformer	Gertsch	TA-40	1	1	1			
	Transformer	Gertsch	TA-134				1	1	1
13	Coupling and Shaft Assembly	Gertsch	AA-196-1	1			1		
	Coupling and Shaft Assembly	Gertsch	AA-196-2		1	1		1	1
14	Resistor, Variable, 25 ohms, 10 turns	Helipot	A25L-5	1			1		
	Resistor, Variable, 25 ohms, 1 turn	Gertsch	RV-14		1			1	
	Resistor, Variable, 5 ohms, 1 turn	Gertsch	RV-25-3			1			1
15	Terminal	Sealectro	FT1550DT4R	3	3	3	3	3	3
16	Fuse, 1-1/2 amp	Bussman	MOL 1-1/2	2	2	2	2	2	2
17	Fuseholder	Bussman	4405	2	2	2	2	2	2
18	Resistor, composition, 1K ± 10%, 1/2 w			1	1	1	1	1	1
19	Resistor, composition, 470 ohms ± 10%, 1/2 w			2	2	2	2	2	2

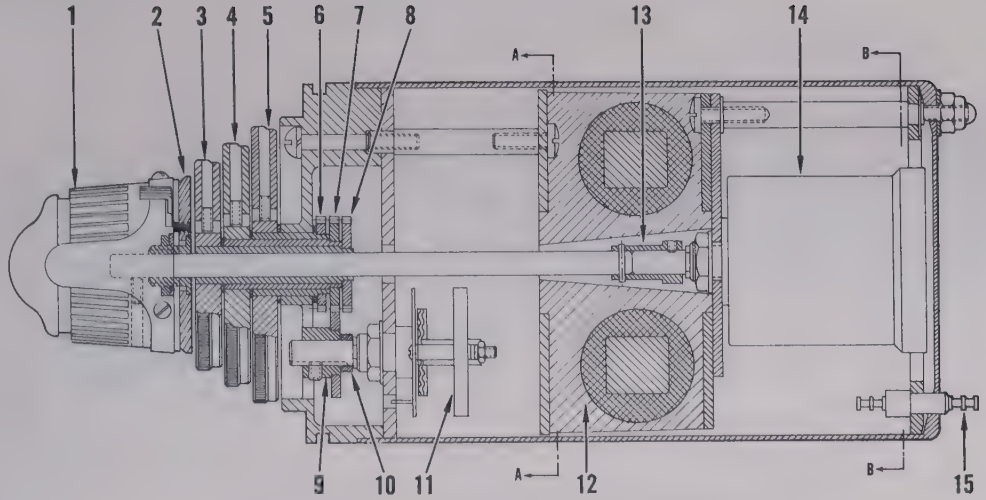


Figure 6-1. Layout of Parts, Model CRT-1 (Sheet 1 of 2)

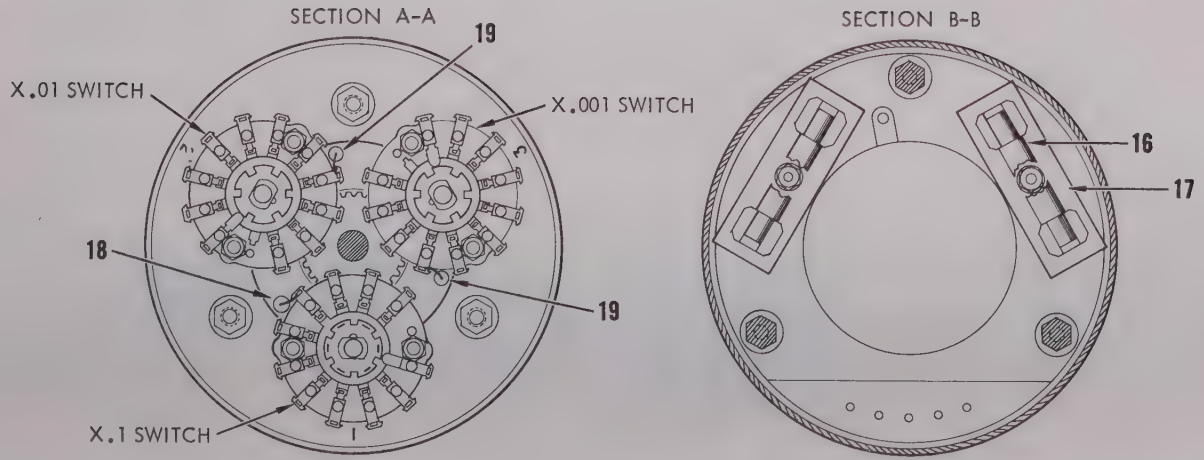


Figure 6-1. Layout of Parts, Model CRT-1 (Sheet 2 of 2)

SECTION VII PARTS LIST

MODEL CRT-3, 3A, 3AB, 3AC, 3B, 3C, 3D, 3E, 3F, 3H, 3J, and 3R (See figure 7-1.)

NO.	ITEM	MFR	PART NO.	-3	-3A	-3AB	-3AC	-3B	-3C	-3D	-3E	-3F	-3H	-3J	-3R
1	Knob Assembly	Gertsch	AA-201	1	1	1	1								1
	Knob and Dial Assembly,X.0001	Gertsch	AA-191-1						1				1	1	
2	Spring	Gertsch	OM-470	2	2	2	2								2
3	Dial and Hub Assembly	Gertsch	AA-200	1	1	1	1								1
4	Yoke	Gertsch	AC-25	1	1	1	1		1	1		1	1	1	1
	Yoke	Gertsch	AC-35					1			1				
5	Knob and Dial Assembly,X.001	Gertsch	AW-5	1	1	1	1	1	1	1	1	1	1	1	1
6	Knob and Dial Assembly,X.01	Gertsch	AW-2	1	1	1	1	1	1	1	1	1	1	1	1
7	Knob and Dial Assembly,X.1	Gertsch	AW-3	1	1	1		1	1	1	1	1	1	1	1
	Knob and Dial Assembly,X.1	Gertsch	AW-393				1								
8	Shaft and Gear Assembly,X.1	Gertsch	AA-181	1	1	1	1	1	1	1	1	1	1	1	1
9	Shaft and Gear Assembly,X.01	Gertsch	AA-182	1	1	1	1	1	1	1	1	1	1	1	1
10	Shaft and Gear Assembly,X.001	Gertsch	AA-183	1	1	1	1	1	1	1	1	1	1	1	1

NO.	ITEM	MFR	PART NO.	-3	-3A	-3AB	-3AC	-3B	-3C	-3D	-3E	-3F	-3H	-3J	-3R
11	Pinion	Gertsch	OM-417	1	1	1	1								1
12	Pinion	Gertsch	OM-418	1	1	1	1								1
13	Shaft Assembly	Gertsch	AA-184-1	1	1	1	1								1
	Shaft Assembly	Gertsch	OM-184-4		1										
	Shaft Assembly	Gertsch	AA-197						1					1	
	Shaft Assembly	Gertsch	AA-197-2												1
14	Hub and Gear Assembly, X.1 and X.01	Gertsch	AA-190	2	2	2	2	2	2	2	2	2	2	2	2
	Hub and Gear Assembly, X.001	Gertsch	AA-189	1	1	1	1	1	1	1	1	1	1	1	1
15	Switch	Gertsch	SW-25	3					4	3		3	4	1	3
	Switch	Gertsch	SW-20		3		3	3			3			3	
	Switch	Gertsch	SW-105			3									
16	Transformer	Gertsch	TA-39-1	1	1		1								1
	Transformer	Gertsch	TA-226			1									
	Transformer	Gertsch	TA-43-1					1							
	Transformer	Gertsch	TA-43-2								1				
	Transformer	Gertsch	TA-41						1						
	Transformer	Gertsch	TA-42-1							1					
	Transformer	Gertsch	TA-42-2									1			

NO.	ITEM	MFR	PART NO.	-3	-3A	-3AB	-3AC	-3B	-3C	-3D	-3E	-3F	-3H	-3J	-3R
	Transformer	Gertsch	TA-122										1		
	Transformer	Gertsch	TA-189											1	
17	Resistor, variable, 25 ohms ± 5%, 1 turn	Gertsch	RV-17	1											1
	Resistor, variable, 5 ohms ± 5%, 1 turn	Gertsch	RV-36		1	1	1								
	Resistor, variable, 1 ohm ± 1%, 1 turn	Kelvin	EP-21						1						
18	Terminal, flash gold	Sealectro	FTM-7	4	4	4	4	4	4	4	4	4	4	4	4
19	Terminal, flash gold	Sealectro	SKT-5BC	4	4	4	4	4	4	4	4	4	4	4	4
20	Terminal	Lerco	3015-B	1	1	1	1	1	1	1	1	1	1	1	1
	Terminal, black (not shown)	Kulka	410-6					1	1		1		1		
	Terminal Lug (not shown)	Gertsch	OM-462					6	6		6		6		

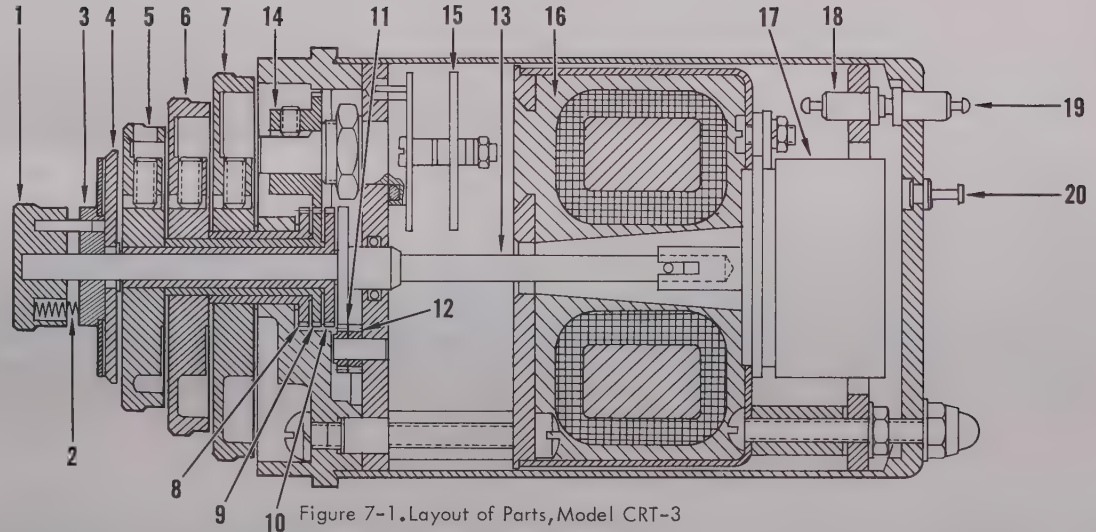


Figure 7-1. Layout of Parts, Model CRT-3

SECTION VIII PARTS LIST

MODEL CRT-4, 4A, 6, and 6B (See figure 8-1.)

NO.	ITEM	MFR	PART NO.	-4	-4A	-6	-6B
1	Counter	Kilo-Dial	Q122	1	1		
	Knob and Dial Assembly	Gertsch	AA-191-2			1	
	Knob and Dial Assembly	Gertsch	AA-543				1
2	Yoke	Gertsch	AC-41	1	1		
	Yoke	Gertsch	AC-25			1	1
3	Knob and Dial Assembly,X.001	Gertsch	AW-5	1	1	1	1
4	Knob and Dial Assembly,X.01	Gertsch	AW-2	1	1	1	1
5	Knob and Dial Assembly,X.1	Gertsch	AW-3	1		1	1
	Knob and Dial Assembly,X.1	Gertsch	AW-4		1		
6	Shaft and Gear Assembly,X.1	Gertsch	AA-181	1	1	1	1
7	Shaft and Gear Assembly,X.01	Gertsch	AA-182	1	1	1	1
8	Shaft and Gear Assembly,X.001	Gertsch	AA-183	1	1	1	1

NO.	ITEM	MFR	PART NO.	-4	-4A	-6	-6B
9	Hub and Gear Assembly, X.1 and X.01	Gertsch	AA-190	2	2	2	2
	Hub and Gear Assembly, X.001	Gertsch	AA-189	1	1	1	1
10	Switch	Gertsch	SW-25	3	3	3	3
11	Potentiometer Assembly	Gertsch	AA-251	1	1		
	Shaft Assembly	Gertsch	AA-184-2			1	
	Shaft Assembly	Gertsch	AA-184-6				1
12	Transformer	Gertsch	TA-39-2	1			
	Transformer	Gertsch	TA-39-3		1		
	Transformer	Gertsch	TA-39-1			1	
	Transformer	Gertsch	TA-39-4				1
13	Resistor, variable, 25 ohms ± 5%, 10 turn	Spectrol	510	1	1		
	Resistor, variable, 25 ohms ± 5%, 1 turn	Gertsch	RV-17			1	
	Resistor, variable, 25 ohms + 5%, 1 turn	Gertsch	RV-52				1
14	Terminal	Sealectro	FTM-7	4	4	4	4
15	Terminal	Sealectro	SKT-5BC	4	4	4	4
16	Terminal	Lerco	3015-B	1	1	1	1

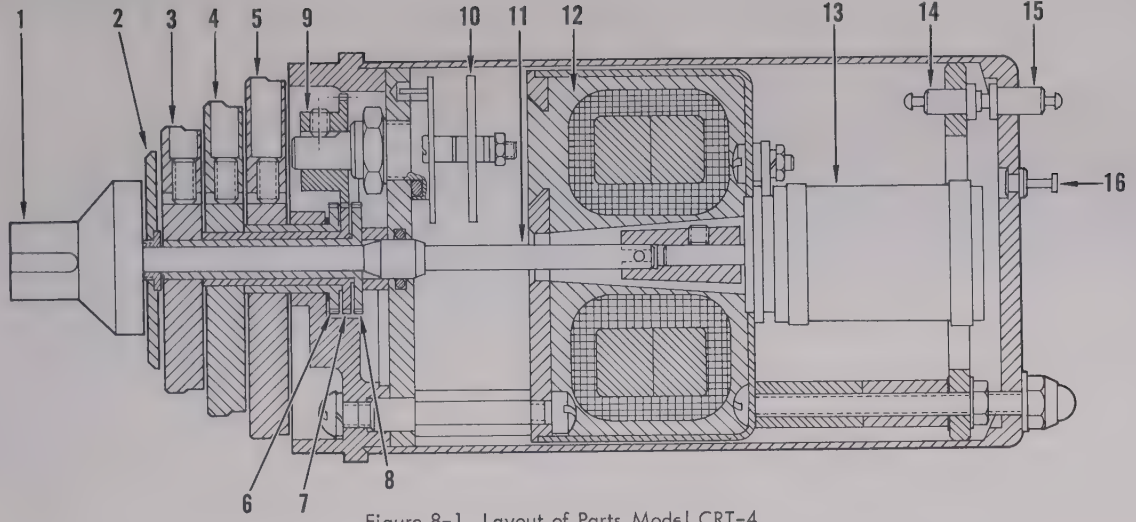


Figure 8-1. Layout of Parts, Model CRT-4

SECTION IX PARTS LIST

MODEL CRT-5A, 5B, and 5C (See figure 9-1.)

NO.	ITEM	MFR	PART NO.	-5A	-5B	-5C
1	Yoke	Gertsch	AC-25	1	1	1
2	Knob and Dial Assembly,X.001	Gertsch	AW-255	1	1	1
3	Knob and Dial Assembly,X.01	Gertsch	AW-2	1	1	1
4	Knob and Dial Assembly, X.1	Gertsch	AW-3	1		
	Knob and Dial Assembly, X.1	Gertsch	AW-318		1	
	Knob and Dial Assembly, X.1	Gertsch	AW-319			1
5	Shaft and Gear Assembly, X.1	Gertsch	AA-181	1	1	1
6	Shaft and Gear Assembly, X.01	Gertsch	AA-182	1	1	1
7	Hub and Gear Assembly	Gertsch	AA-190	2	2	2
8	Switch	Gertsch	SW-25	2	2	2
9	Shaft Assembly	Gertsch	OM-685-1	1	1	1
10	Transformer	Gertsch	TA-166	1	1	1
11	Resistor, variable, 15 ohms ± 5%, 1 turn	Gertsch	RV-37	1	1	1

NO.	ITEM	MFR	PART NO.	-5A	-5B	-5C
12	Terminal	Sealectro	FTM-7	4	4	4
13	Terminal	Sealectro	SKT-5BC	4	4	4
14	Terminal	Lerco	3015-B	1	1	1

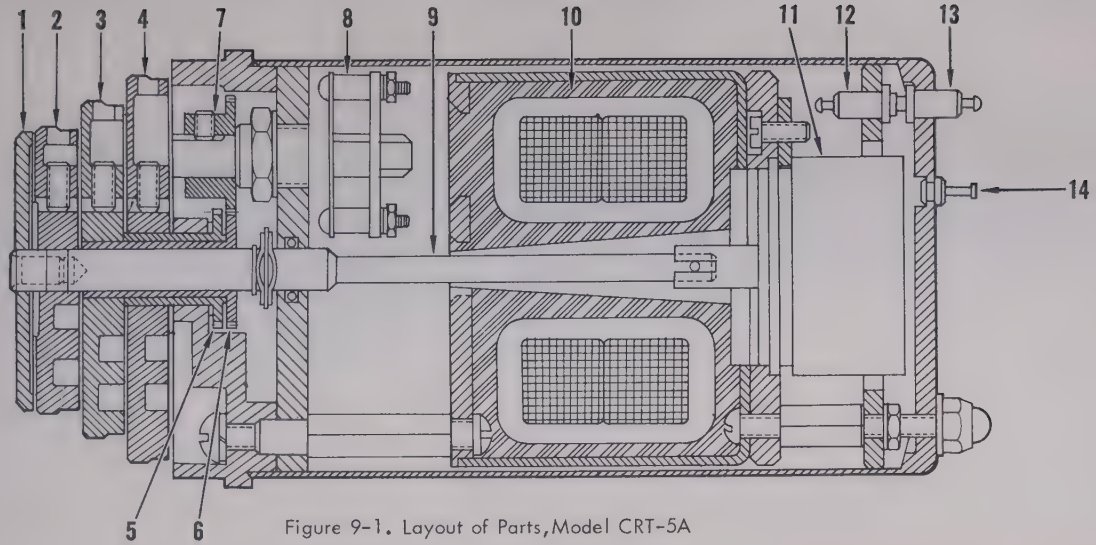


Figure 9-1. Layout of Parts, Model CRT-5A

SECTION X PARTS LIST

MODEL CRT-7 (See figure 10-1.)

NO.	ITEM	MFR	PART NO.	QTY
1	Knob and Dial Assembly	Gertsch	AA-543	1
2	Yoke	Gertsch	AC-25	1
3	Knob and Dial Assembly	Gertsch	AW-343	1
4	Knob and Dial Assembly	Gertsch	AW-342	1
5	Knob and Dial Assembly	Gertsch	AW-341	1
6	Shaft and Gear Assembly	Gertsch	AA-181	1
7	Shaft and Gear Assembly	Gertsch	AA-182	1
8	Shaft and Gear Assembly	Gertsch	AA-183	1
9	Hub and Gear Assembly, X.1 and X.01	Gertsch	AA-190	2
10	Hub and Gear Assembly, X.001	Gertsch	AA-189	1
11	Resistor, composition, 47 ohms ± 10% (X.01, X.001)			2

NO.	ITEM	MFR	PART NO.	QTY
	Resistor, composition, 1K ± 10% (X.1)			1
12	Switch	Gertsch	SW-91	3
13	Transformer	Gertsch	TA-191	1
14	Shaft Assembly	Gertsch	AA-542	1
15	Coupling	Gertsch	OM-797	1
16	Resistor, variable, 5 ohms, 1 turn	Gertsch	RV-25-2	1
17	Terminal	Sealectro	FTM-7	5
18	Terminal	Sealectro	SKT-5BC	5
19	Terminal	Lerco	3015-B	1
20	Terminal Block	Kulka	410-6	1
21	Terminal Lug	Gertsch	OM-462	6

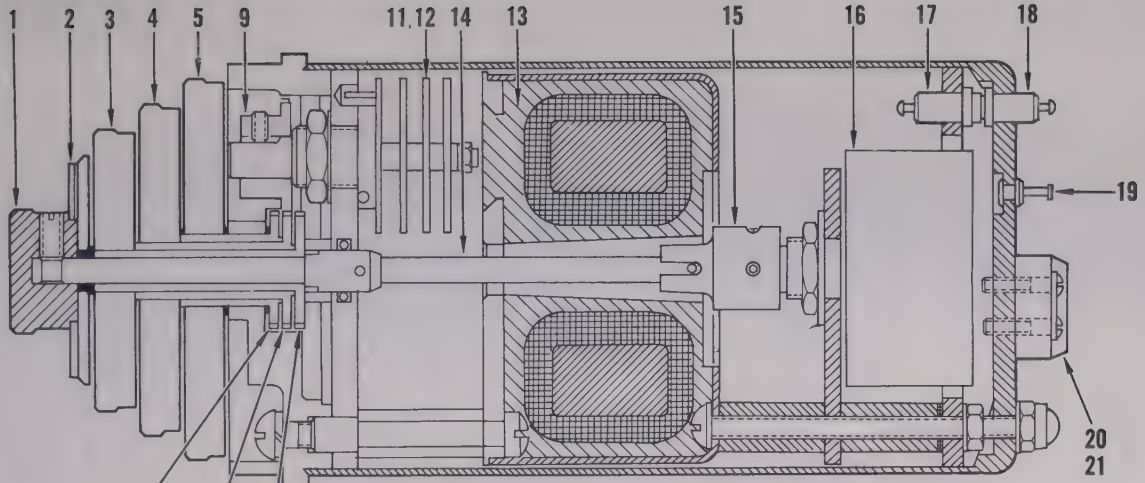


Figure 10-1. Layout of Parts, Model CRT-7

INDEX TO RatioTran* ENGINEERING BULLETINS

BULLETIN NO.	SUBJECT
1	Theoretical Analysis of Accuracy of Ratio Transformers
2	Use of Gertsch Standard Ratio Transformers for Low Impedance Voltmeter Calibration
3	Accuracy Calculations for Gertsch Standard Ratio Transformers
4	Use of RatioTran* in Bridge Circuits
5	Measuring Small Phase Angles

* *Trademark*

THEORETICAL ANALYSIS OF ACCURACY OF RATIO TRANSFORMERS (RatioTran)*

Theoretical analysis of a perfect autotransformer used for stepdown purposes shows that if leakage inductance and winding resistance are uniformly distributed and the turns can be accurately tapped, the accuracy as a voltage divider for no load is perfect.

Consider first the effects of leakage inductance. The most symmetric configuration insofar as flux is concerned is the uniformly wound toroid. By suitably interleaving the windings and carefully maintaining uniformity, the total leakage inductance can be kept to under 10% of the air core inductance. Since the air core inductance is approximately 1/u times the inductance with iron core, where u is the permeability of the core material, the total leakage inductance to coupled inductance ratio is 1/10u. The core material used in the transformers is supermalloy which has a guaranteed initial permeability of 55,000. The leakage to coupled inductance ratio is therefore approximately .0002%. Since this figure represents the ratio of voltage dropped in the leakage inductance to total voltage, the error in the transformer due to non-distributed leakage inductance will not exceed this, if the leakage inductance per turn does not vary by more than ±100%. This condition can be met with suitable techniques of interleaving the windings.

Non-distributed winding resistance has much the same effect as non-distributed leakage inductance. If the effects of winding capacitance are neglected, the winding resistance is most important at low frequencies since the exciting impedance of the transformer is directly proportional to frequency. Since the exciting impedance is fairly reactive, the voltage dropped in the winding resistance will be almost in quadrature with the input and consequently any non-distributed resistance will cause some phase error as well as magnitude error. The fact that this error voltage is in quadrature makes the magnitude error extremely small and for all practical purposes negligible. Typical figures might be .000001% for small ratios and even less for larger ratios. Phase angles from this cause would be approximately .01 milliradians at low frequencies and small ratios decreasing for larger ratios.

At higher frequencies distributed capacitance becomes important. It causes voltage drops in the leakage inductance and winding resistance which are not uniformly distributed due to the transformer action. Like the effects of winding resistance, the errors caused by the capacitance are mainly in quadrature and so cause phase shift at low ratios. Typical values for this phase shift are:

Less than .05 milliradians for frequencies below 1 KC and ratios above .1 for low voltage - high frequency units.

Less than .05 milliradians for frequencies below 200 cps and ratios above .1 for high voltage low frequency units.

Phase angle due to this cause is almost directly proportional to frequency for any particular ratio down to frequencies where the non-distributed resistance takes over.

Other sources of error are:

1. Voltage drops due to exciting current in the leads to the transformer.
2. Loading effects of the potentiometers.
3. Non-linearity and end effects of the potentiometer.

* *Trademark*

The first of these effects may be minimized by using heavy connecting leads or treating the transformer as a four terminal impedance. The internal wiring of the transformers contributes to this error. These effects are worse at higher frequencies, above the self-resonant frequencies of the transformers.

The potentiometers cause some loading effects on the transformers due to the internal impedances of the windings and switch contacts.

For units with the 10 turn potentiometer, such as the RT-1 and Model RT-10, the errors due to this cause are approximately .0001% of the input. In the single turn units this error amounts to about .00001%. The single turn potentiometer causes less error than the 10 turn since the voltage across it is .001% of the input in comparison to .1% across the 10 turn potentiometer.

Non-linearity and end effects of the potentiometer may cause an error of approximately .0005% of the input in the case of the units with the 10 turn potentiometers. The single turn potentiometers may cause an error of .00001% of the input.

From the foregoing considerations a reasonable terminal linearity figure of .001% is derived. The usual definition of terminal linearity is the error in the output divided by the total input:

$$\text{Terminal Linearity} = \frac{\triangle E_o}{E_{IN}}$$

where $\triangle E_o$ is the actual error voltage in the output and E_{IN} is the total input voltage.

An accuracy figure in terms of the output voltage would be

$$\text{Ratio Accuracy} = \frac{\triangle E_o}{E_o}$$

where $\triangle E_o$ is the actual error voltage in the output and E_o is the total output voltage.

When the ratio gets small, the error caused by pot loading, pot non-linearity, and lead drops become predominant. Since these errors are constant in absolute value, their fractional value in terms of the output is inversly proportional to the ratio of the transformer. Taking this into account a reasonable ratio accuracy for the three decade units with the 10 turn pot is:

$$\text{Ratio Accuracy} \pm \left(.001\% + \frac{.0006\%}{R}\right)$$

(This applies to Models RT-1 & 10 and for the 5 decade units, with or without the single turn pot:

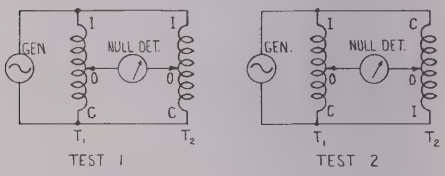
$$\text{Ratio Accuracy} \pm \left(.001\% + \frac{.0001\%}{R}\right)$$

where R is the indicated ratio of the transformer. (This applies to all Models except RT-1 & 10)

Standards suitable for certifying transformers to the accuracy figures quoted are not generally available. It can be seen, however, from the foregoing discussions that the transformers are inherently excellent voltage dividers. They can be considered primary standards of ratio in that one can be constructed by following assembly instructions and requiring no measurements or calibrations other than wiring checks and tests to make certain that the number of turns is correct. A unit so constructed will match any other unit so constructed to well within the specifications

quoted above. The units are ageless, requiring no calibration tests and should perform indefinitely with no loss in accuracy barring some switch failure or actual damage to the transformer.

Tests have been performed on a basis of comparison between several units. While it is not possible to get complete absolute data in this manner, certain facts can be deduced. Referring to the diagram T_1 and T_2 represent the two transformers under test.



Let R_1 be indicated ratio of T_1
R_2 be indicated ratio of T_2

Let E_1 be error in indicated Ratio of T_1
E_2 be error in indicated Ratio of T_2

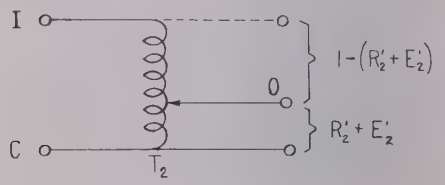
then at balance in Test 1

$R_1 + E_1 = R_2 + E_2$

at Balance in Test 2

$R_1 + E_1 = 1 - (R_2' + E_2')$

where $1 - (R_2' + E_2')$ is the complement of $R_2' + E_2'$ as shown below



Now suppose that in both tests

$R_1 = R_2$

$R_1 = 1 - R_2'$

then $E_1 = E_2$

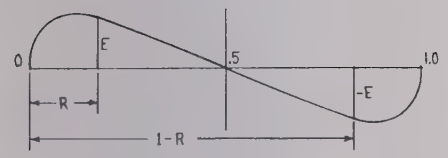
$E_2' = -E_1$

or $E_1' = -E_2$

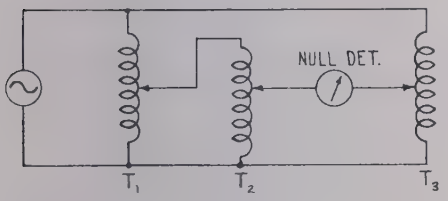
This shows that if at balance in both tests the indicated ratios are exactly equal or complementary there can exist an error of a special nature which cannot be detected.

E at $R = -E$ at $(1-R)$

E must be zero at $R = .5$ and show odd symmetry about $R = .5$



In general, any two transformers so tested will meet the conditions for the tests within 1 or 2 parts in 10^5 so that any components of error which do not show the above symmetry must be at least this small. To obtain some idea of the absolute errors two transformers were cascaded and compared against a third as shown below.



$(R_1 + E_1)\ (R_2 + E_2) = (R_3 + E_3)$ at Balance
if we choose $R_1 = R_2 = .5$
from the foregoing analysis $E_1 = E_2 = 0$

If proper care is taken to compensate for loading effects the magnitude of E_3 can be determined at $R_3 = .25$. This error in general is less than .001%.

This process can be continued by cascading more transformers and measuring the error at points $R = (.5)^N$

It is easy to show that the same analysis applies to quadrature voltage. The same tests can be made and values of 0 at points $R = (.5)^N$ determined. The phase angle data given earlier in this article was derived in this manner.

All of the foregoing discussions apply to completely unloaded conditions on the transformers. Effects of loading are discussed in Engineering Bulletin No. 3 entitled "Accuracy Calculations for Gertsch Standard Ratio Transformers."

Accuracy formulas given above apply only to those units shipped after January 1, 1956. Previous units have accuracies of $\pm(.004\% + \frac{.0006\%}{R})$ and $\pm(.004\% + \frac{.0001\%}{R})$ respectively.

USE OF GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*) FOR LOW IMPEDANCE VOLTMETER CALIBRATION

The RT Series Standard Ratio Transformers are very useful for AC voltmeter calibrations. Basically, the system consists of a standard voltage source driving the RatioTran* which in turn drives the meter to be calibrated.

Several things must be taken into consideration in this system. The source voltage must be known at least as accurately as the calibration to be made. The distortion of the source must be low, particularly in a case where the meter which is monitoring the source measures on a different basis from the meter to be calibrated. For example, the monitoring meter might read RMS voltage and the meter to be calibrated might read average voltage.

The loading effects of the meter to be calibrated on the RatioTran* should be taken into consideration. These loading effects can be easily determined from the ratio of meter impedance to ratio transformer impedance. For all practical purposes the ratio transformer impedance is resistive and forms, with the meter to be calibrated, a voltage divider. Therefore, if the voltmeter is resistive, the voltage appearing across it will be low by an amount equal to the ratio between the RatioTran* resistance and the meter resistance. For example, if the RatioTran* has an internal impedance of 5 ohms and the meter has a resistance of 5,000 ohms, the voltage appearing across the meter will be 5/5000 or .1% lower than it would be if the meter had infinite impedance.

The foregoing analysis can be generalized. The fractional error that will exist with the RatioTran* resistance R and meter resistance M is approximately equal to $\frac{R}{M}$, or stating it a different way, for a maximum error E the meter resistance M must be greater than $\frac{R}{E}$, where R is again the series impedance of the RatioTran.*

The maximum series impedance in any of the ratio transformers for nominal frequencies is less than 5 ohms with the exception of the RT-1 and RT-10 where the maximum is 12 ohms. Consequently, for meter impedance of 5,000 ohms or greater the error introduced by loading effects on the ratio transformers will not be greater than .1% for all ratio transformers except the RT-1 and RT-10, in which case for the same accuracy the meter resistance must not be less than 12,000 ohms.

If greater accuracies are desired or the meter impedance is lower than the values given above, power must be supplied to the meter in a bridge arrangement shown in Figure 1. With this circuit it is possible to adjust the variable series impedance so that all the power supplied to the meter comes from this branch. This, of course, occurs when the bridge is balanced, that is, the ratio of the meter impedance to the total impedance (meter impedance plus variable impedance) is equal to the ratio of the Standard Ratio Transformer. Obviously, when the bridge is balanced there is no current flow through the ratio arm of the transformer and the junction between the series impedance and the meter so there is effectively no load on the ratio transformer.

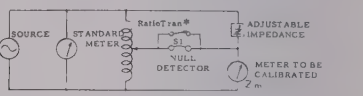


FIG. 1

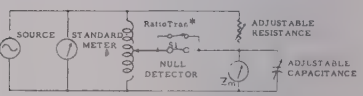


FIG. 1A
Modification of Fig. 1
CONVENIENT WHEN Z_m CONTAINS INDUCTIVE REACTANCE

* *Trademark*

Since we can make the ratio transformer operate essentially unloaded by this method, meters with impedance as low as desired can be calibrated with no loss in accuracy.

One other restriction must be placed on the variable impedance in series with the meter. It must have the same phase angle as the meter. The total requirement can be stated generally as follows: the ratio of the complex impedances of a meter and series impedance must be real and equal to $\frac{N}{N-1}$ where N is the ratio on the ratio transformer. Here we have assumed that the Ratio Transformer has zero phase shift.

This last statement is merely another way of saying that the bridge formed must be balanced.

The degree of unbalance which can be tolerated in the bridge circuit can best be expressed in terms of the unbalanced current flowing in the ratio arm of the transformer. Since the product of the unbalanced current times the effective impedance in the ratio arm gives the magnitude of the error voltage, the maximum value of this current can be easily determined. It would be simply E Max. divided by R Max. where E is the maximum allowable error voltage and R is the maximum series impedance in the ratio arm of the transformer.

The unbalanced current itself may be measured directly with a high sensitivity AC current meter, or the bridge may be brought to balance with standard null detector techniques. The null detector should be shorted out with switch, S1, after balance has been reached. This last step is recommended since the voltage at the junction between the series impedance and the meter will always be closer to the true voltage for small errors if the null detector is shorted out.

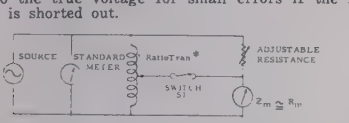


FIG. 2

SUITABLE ONLY WHEN Z_m IS RESISTIVE OR NEARLY RESISTIVE

If the phase angle of the meter is known to be small this series impedance may be resistive and balance of the bridge can be detected with a circuit shown in Figure 2. The switch, S_1, is alternately opened and closed and the series impedance adjusted so that the meter reads the same whether the switch is opened or closed. When this occurs the bridge is balanced provided the phase angle of the meter is small. The phase angle requirement must be met because it is possible, in this test, for the meter to read the same whether the switch is opened or closed and still not have the voltage across it equal to the open circuit voltage of the ratio transformer, when the phase angle of the meter in the series impedance are not equal. The allowable phase angle can be determined from the circuit constants and the accuracy desired, or a direct measurement of the unbalanced current may be made.

For maximum accuracy of calibration the RatioTran* should not be used to divide the standard source too far. The reason for this is, the accuracy of the ratio decreases for small ratios between output and input of the RatioTran.* To guarantee accuracies better than .02% it would be necessary to operate with ratios larger than .01. To extend the system range below .01 a new standard voltage one 100th the original standard voltage could be derived with the RatioTran* and this used to extend the system on down by another factor of 100. In this manner a total range of 10,000 to 1 can be covered with less than .04% error. One method of doing this is to connect two ratio transformers in cascade. The percentage errors of the two transformers can be added in this case.

ACCURACY CALCULATIONS FOR GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*)

1. DEFINITION

The accuracy of Gertsch Standard Ratio Transformers is specified by a formula which gives the maximum error which could be expected in the indicated ratio. This would give the error as a percentage of the output if the input is perfectly known. This accuracy is applicable to a bridge circuit, since the source voltage is common to both branches of the bridge circuit and variations of source voltage cause no error. The accuracy specification is given as a formula similar to $\pm$ $(.004\% + \frac{.0001\%}{R})$ where R

	ERROR EXPRESSED AS PERCENTAGE OF OUTPUT		
Ratio =	Ratio Transformer Units Shipped Prior to 1/1/56 $\pm(.004\% + \frac{.0001\%}{R})$	Ratio Transformer Units Shipped After 1/1/56 $\pm(.001\% + \frac{.0001\%}{R})$	Potentiometer .005% Terminal Linearity
1.0	± .0041%*	± .0011%*	± .005%
.1	± .005%	± .002%	± .05%
.01	± .014%	± .011%*	± .5%
.001	± .104%*	± .101%*	± 5%

*This is the exact solution of the formula. Since "error" is only roughly specified, all digits beyond the first significant figure are meaningless.

* *Trademark*

is the indicated ratio in the decimal fraction form with which the RatioTran® switches are calibrated. This formula gives a more accurate description of the maximum error which could be expected from a Gertsch RatioTran® than would be obtained by the standard definition of terminal linearity. In a potentiometer terminal linearity rating, the error component which is to be expected at the output is quoted as a percentage of the input voltage. A comparison of the specified maximum error in a RatioTran® and a potentiometer of .005% terminal linearity is given in the following table.

2. ACCURACY vs AGE

A careful study of the distribution of resistance and reactance in RatioTrans® leads us to believe that it is extremely improbable that the specified values of error will ever be exceeded. The accuracy of Gertsch RatioTrans® does not change appreciably with age and periodic calibration checks are unnecessary. Any periodic checks should be directed chiefly at detecting malfunctioning switches or potentiometers.

3. ACCURACY UNDER LOAD

Gertsch Standard Ratio Transformers have an internal impedance which can be considered to be in series with the output (see Fig. 1).

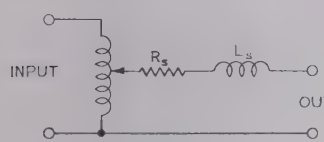


FIG. 1

The value of this impedance varies with ratio in a manner which makes it impractical to define it as a function of ratio. Instead, maximum values of resistance and reactance that can be expected at the worst possible setting of the instrument are given. Voltage drop in the RatioTran® will always be less than the value found by multiplying the load current by the specified maximum series impedance. If the impedance of the load is known, the error introduced by this impedance will always be less than the ratio of the specified maximum impedance to the load. As a numerical example, suppose that a 10,000 ohm resistive load is to be driven from a Model RT-5 operating at 400 cycles. The RT-5 has a maximum effective series inductance of 75 uh. At 400 cycles this is an inductive reactance of .2 ohms, and, for the purposes of this problem, it may be neglected since it is much less than the 3 ohms maximum effective series resistance. The RT-5 may be assumed to have a series impedance of 3 ohms or less resistive. When loaded by 10,000 ohms, the fraction of output voltage dropped across the internal impedance of the RT-5 is given by:

$$\frac{E\text{drop}}{E\text{out}} = \frac{R\text{series}}{R\text{load} + R\text{series}} = \frac{3}{10{,}000 + 3} \approx \frac{3}{10{,}000} = .0003 = .03\%$$

In this case the percentage error contributed from this source is .03%. If this error is acceptable, the circuit may be used. Otherwise a bridge circuit must be devised which will drive the required load impedance without loading the Ratio Transformer beyond the acceptable current level. Circuits for this purpose are discussed in another paper distributed by Gertsch Products, Inc. The title of this paper is Engineering Bulletin No. 2 (RatioTran) "Use of Gertsch Standard Ratio Transformers For Low Impedance Voltmeter Calibration."

USE OF RatioTran* IN BRIDGE CIRCUITS

Since any bridge circuit has four terminals, only one of which may be grounded, it is recommended that a shielded bridge transformer such as the Gertsch Model ST100 or ST100A be used to isolate either the generator or detector. Typical circuits are shown below.

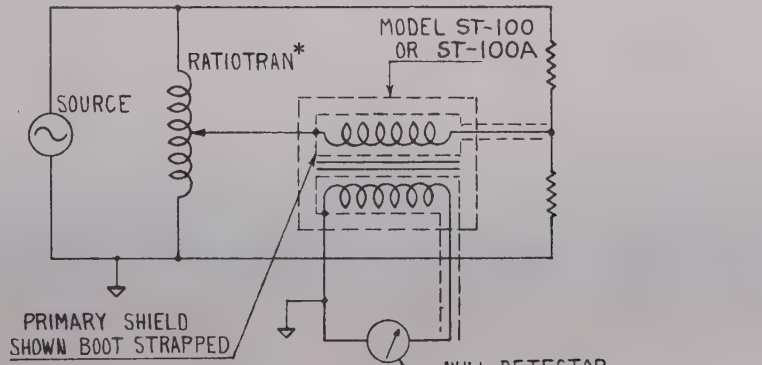


FIG. 1

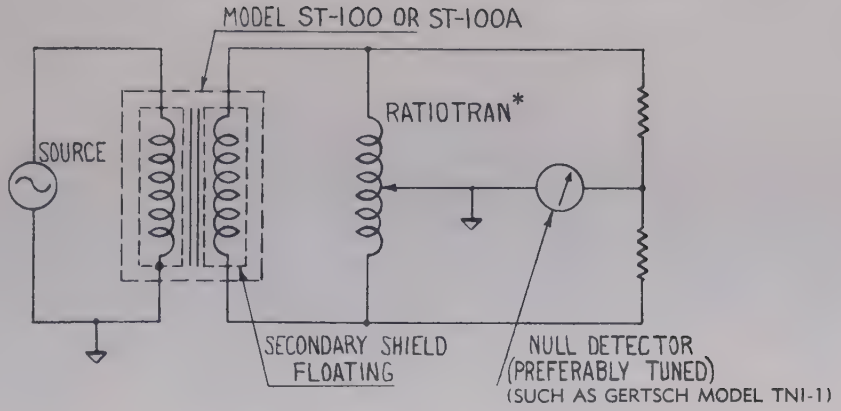


FIG. 2

The degree of shielding of the various bridge elements used depends on impedances and accuracy desired. For a good treatment on AC Bridge technique the reader is referred to "Electronic Measurements" - Terman & Pettit.

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The following article originally appeared in the January 1956 issue of Control Engineering and is reprinted here with the permission of Control Engineering and the author, Mr. Jack Gilbert.

Measuring Small Phase Angles

JACK GILBERT, Norden Laboratories

Phase shift due to potentiometers, precision resistors, computer amplifiers, ac tachometers, and transformer windings can be found by a relatively simple technique that can measure phase angles as small as 0.005 deg and as large as 30 deg. With some loss of accuracy, angles up to 90 deg can also be detected by the method. The detection circuit, with elements of only conventional accuracy, obtains phase shift and quadrature voltage from a reference voltage varying from 50 to 5,000 cps. And the result is accurate to plus or minus 0.01 deg plus or minus 5 per cent at midband (350—1000 cps).

The reference voltage, E, is divided by the reference pot slider until a minimum or null reading is observed on the vacuum tube voltmeter. This voltmeter reading will be the quadrature voltage. The phase shift created by the reference pot is insignificant because of its relatively low impedance and internal construction. Figure 1 illustrates the circuit and Figure 2 its theory of operation.

The voltage ratio X is read directly from the dial of the reference pot, and the null voltage from the meter. An infinite resolution slide-wire type pot is desirable for

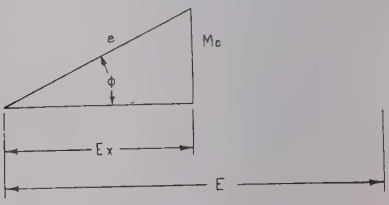

FIG. 2

the reference voltage divider. The phase shift is an angle whose tangent is equal to Mo/EX. For angles less than 6 deg, multiply the ratio Mo/EX by 57.3 deg to calculate a

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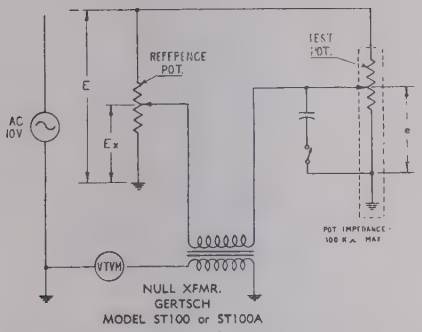

FIG. 1

phase angle within the accuracy of the measurement technique. If a constant reference source is used, the dial of the voltmeter can be calibrated in phase shift directly.

It will be noted that as the phase angle becomes smaller, variations in *EX* produce an increasingly greater role in the variations of *Mo*. Hence, the accuracy of the technique for small angles is exceeded by its sensitivity. To achieve the indicated accuracy of 5 per cent, the reference pot should be accurate to ¼ per cent for angles less than 1 deg and the meter calibrated within 3 per cent.

For potentiometers, a small capacitor may be switched across the test component to determine the polarity (lead or lag) of the shift. The change in meter reading is then indicative of the polarity of the phase angle. For instance, if the shift is caused by capacitative reactance of the tested part, the condenser will augment them, increasing the negative phase shift and hence the null voltage. Similar techniques may be used for other components.

A plot of the phase shift of an unloaded ten-turn potentiometer can be easily calculated once its time con-

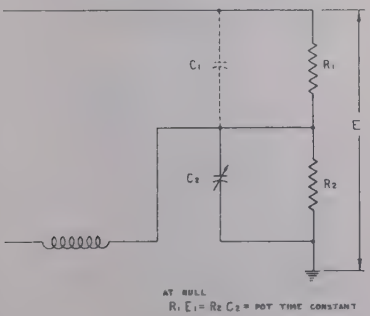

FIG. 3

stant is known. The time constant could be found by suitable calculation involving the phase shift measurements (obtainable by the balancing technique), but here is a direct way of finding it.

Figure 3 shows the setup R_1 is the entire ten-turn pot. R_1C_1 is the time constant produced by the distributed capacity of the pot. C_2 is a variable capacitor, and R_2 a small fixed resistor of approximately the same resistance as the pot. The phase shift through this resistor is too small to be significant. Only when the adjustable capacitor, C_2 is such that R_2C_2 equals R_1C_1 is the output voltage in phase with the input voltage. With the reference pot set near its halfway point, the in-phase component of the voltage will equal the voltage EX, but will be out of phase with EX depending on the time constant of R_1C_1.

This time constant can now be used in the following equation to find the quadrature voltage of any of the ten-turn pot's shaft settings.

$Mo = EwRC\ (1-2S)\ (1-S)\ (S)$

E = input voltage

w = radian frequency

R = potentiometer overall resistance

C = equivalent lumped capacity measured across end terminals

S = shaft position, in per cent of maximum rotation.

Similarly, one can calculate phase shift (in radians) by

$\varnothing = wRC\ (1-2S)\ (1-S)$

Since similar expressions can be derived for other pot types, one reading provides all the information needed to plot a pot's phase shift characteristics.

Rather than a slide-wire pot, an ideal standard voltage divider is a Gertsch Ratio Standard, Model RT-5. Resolution better than 0.0001 per cent is available together with a voltage ratio accurate to within 0.004 per cent. The advantage of this item is accurate output with very low internal impedance and extremely low phase shift.

The following additional information is supplied by the Engineering Department of Gertsch Products, Inc.

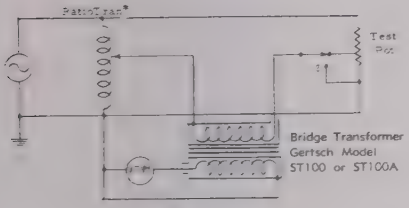

FIG. A

The circuit shown in Fig. A is a variation on the method described in the preceding article. Leads may be changed instead of using a switch.

In operation, the RatioTran® is adjusted to the best null with the switch in position 1. The RatioTran® then reads the inphase component of voltage ratio. The VTVM is read and the switch thrown to position 2. The RatioTran® is then adjusted to bring the VTVM back to the same reading. The RatioTran® then reads the quadrature component of the unknown ratio. This method has the advantage of eliminating errors from the null transformer voltage ratio. Also, the source voltage need not be accurately known.

A possible source of error when measuring phase angles by this method is the loading on the bridge caused by the null transformer and null detector. The method depends on measuring the remaining voltage at the best null. This voltage will be reduced because of current through the primary of the null transformer. Unless the impedance of the device under test is low compared to the impedance of the null transformer primary, the error will be serious. The circuit of Fig. B can be used to reduce this effect since a high impedance VTVM may be used directly as a null detector.

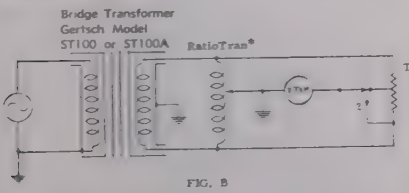

FIG. B

The bridge transformer may be omitted in this circuit if the source is capable of satisfactory operation as a floating source.

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